LRFD

3-7 DESIGN DATA DOCUMENTATION AND EVALUATION OF ANOMALOUS CIDH CONCRETE PILES

Introduction

Cast in Drilled Hole (CIDH) and Cast in Steel Shell (CISS) concrete piles are commonly used when large vertical or lateral resistance is required. When ground water is anticipated CIDH piles must be at least 2 feet in diameter and must be inspected by Gamma-Gamma Logging (GGL) and sometimes by Cross-hole Sonic Logging (CSL). Memo to Designers 3-1 (MTD 3-1) provides guidelines for the required number of inspection tubes and the proper placement of the tubes to improve constructability. MTD 3-1 requirements for placement of inspection tubes may force the designer to use bundled bars or increase the size of the pile. Use of construction joint with permanent casing at column-to-shaft connection will reduce the chance of anomalies in Type-II shafts. Refer to MTD 3-1 and Construction Standard Specifications for further details.

The Foundation Testing Branch (FTB) of Geotechnical Services (GS) performs GGL and CSL on CIDH piles together with other Quality Assurance (QA) procedures. The main objective of GGL is to investigate uniformity of concrete density, where significant reduction in density identifies anomalies. When defects are detected Structure Design (SD), GS and Corrosion Technology Branch of the Materials Engineering and Testing Services (METS) are contacted. The information required for structural evaluation of an anomaly should be prepared during the design phase to meet the short timeframe requirements specified in the Construction Standard Specifications. This memo provides guidelines for documentation of the design data, the structural evaluation process of a rejected pile, and an example to clarify the process.

CIDH Shaft Design Data Documentation

If slurry displacement method is used to construct CIDH piles, the Foundation Testing Branch of the GS will perform non-destructive testing to evaluate homogeneity of the concrete pile. When the testing detects an anomaly the pile is rejected. Office of Structure Construction collects design information from GS, Corrosion Technology Branch of METS, and SD to evaluate the rejected pile. Gathering this information is required to determine if the pile is “adequate” or “inadequate” with the anomaly in place.

Structure Design must complete structural evaluation within the timeframe specified in the contract's special provisions, or the State may incur costs associated with Section 8-1.09 "Right of Way Delays", of the Standard Specifications. To prevent such delays, the Project Engineer shall compile the necessary design information for each CIDH concrete pile during the PS&E phase of the project. The information shall be retained in the project files and must be easily accessible during the construction phase.

This information includes "Factored Shear Force and Bending Moment Diagrams" along the pile length, together with shear and moment capacities assuming no anomaly is present. The designer will need to envelope the maximum shear, moment, and axial demands that may occur during the life of the structure for different limit states, construction stages, and also combinations of scour and liquefaction (if applicable). Shear and flexural capacities of the defective shaft are also required for structural evaluation, however this portion cannot be completed until the location and size of the anomaly is known.

Pile Design Data Form (PDDF)

After the contractor has constructed a CIDH concrete pile using the slurry displacement method, FTB will perform California Test Method (CTM) 233 – "Method for Ascertaining the Homogeneity of Concrete in CIDH Piles Using the Gamma-Gamma Test Method". If acceptance testing performed by the engineer determines that a pile does not meet the requirements of the specifications of CTM 233, Part 5C, then the pile will be rejected.

After the pile has been rejected the State has a limited amount of time to make a determination on which of the following options are available to the contractor for dealing with the rejected pile:

1) The pile must be supplemented or replaced.
2) The pile must be repaired.
3) The pile is adequate with the anomaly left in place.

The FTB will complete part 1 of the Pile Design Data Form (see Bridge Construction Memo 130-10 – Attachment No. 2). This information will identify the severity and the location of the anomaly within the pile and will be used by GS to complete Part 2, SD to complete Part 3, and the Corrosion Branch to complete Part 4 of the form.

Once the location of the anomaly has been identified in Part 1, then Structure Design can complete Part 3 of the form, which will require the following information:

a) As designed shear and moment capacities at the location of the anomaly. These values are calculated during the design phase assuming that the pile would not contain any defects.

b) The shear and moment demands at the location of the anomaly. This information should be readily available to the Structure Design personnel conducting construction support, since it may be time consuming to reproduce this data.

c) The reduced shear and moment capacities of the defective shaft at the location(s) of the anomaly. This step will be explained in the evaluation example.

d) Determination if the pile is structurally adequate with the anomaly left in place. Structure Design will make this determination using the information above and engineering judgment considering uncertainty in the nature of the anomaly. It is important to point out that the State is not allowed additional time to perform this evaluation.

If the pile is determined to be adequate with the anomaly in place, then the contractor may choose to repair the pile and receive full payment or leave the anomaly and incur an administrative deduction specified in the contract.

If the pile is determined to be inadequate then the anomaly mitigation must be addressed. Foundation Testing, Structure Construction, and Structure Design will determine if the pile can be repaired or if the pile must be supplemented or replaced. Standard repair techniques are excavation to replace the suspect concrete, and grouting repair.

Structural Evaluation of Anomalous Piles

In general, structural evaluation of the pile at the anomaly location includes comparing reduced bending, shear and axial capacities to corresponding strength and extreme event (seismic) demands. However, for pile groups in competent soil limited bending is developed in the pile, and therefore evaluation will be limited to axial and shear capacity checks.

The evaluation should be performed with and without scour and liquefaction effects, if applicable. Therefore, up to four different combinations must be considered. In the design phase the location of the potential anomaly is unknown, therefore demands for all applicable cases must be compiled and recorded as moment and shear diagrams or tables for the entire length of the pile. Factored axial load that is equivalent to factored nominal compression resistance of the pile can be easily extracted from the Pile Data Table. The information will be saved in the design branch for the construction support phase.

GGL results specify number of tubes with unacceptable low concrete density readings, therefore designer may conservatively eliminate the tributary slice(s) corresponding to tubes with low readings. CSL results may provide more detailed information about the size of the anomaly and will improve strength evaluations. Below is a summary of the typical structural evaluation process for anomalous pile shafts and CIDH pile groups prone to liquefaction:

- Use sectional analysis software (such as X-Section Program) to calculate the flexural capacity of the anomalous pile (M_{ne} or M_p). If a single tube or multiple adjacent tubes have low readings, the corresponding tributary slice(s) will be assumed as voided (without concrete and rebar) and flexural capacity will be calculated in a direction that causes compression in the lost slice(s) of the section. When multiple non-adjacent tubes show unacceptable low readings, flexural capacity must be assessed in different directions (30 degree intervals), and the miniimum value should be used.
- Considering approximations in assessing the size of the anomaly, acceptance criteria for bending and shear under the Extreme Event (seismic) Limit State is as follows:

Type-II Shafts

The moment and shear checks are summarized as $M_d \leq M_{ne}$ and $V_d \leq \varphi V_n$, where M_d and V_d are seismic moment and shear demands at the location of the anomaly when applying overstrength moment (M_o) to the column. M_{ne} is the expected nominal moment of the shaft at the location of the anomaly, and φV_n is the factored nominal shear resistance of the pile as defined in Caltrans' Seismic Design Criteria (SDC 3.6.7). In calculation of shear resistance of concrete (V_c), the cross section of the shaft is reduced in proportion to the size of the anomaly. Since the detected anomaly indicates concrete with lower density rather than void, the confinement reinforcement is assumed functional when calculating V_s.

Type-I Shafts, Pile Groups in Liquefied Soil (if plastic hinges form in the piles)

Seismic moment demand (M_d) at the location of the anomaly should be less than $1.25M_p$ for multi-column bents and $1.15M_p$ for single column bents. M_p is the plastic moment of the reduced shaft cross section at the location of the anomaly. Seismic shear demand at the location of the anomaly shall be less than the nominal shear resistance of the pile (φV_n), as defined in SDC 3.6.1. In calculation of shear resistance of concrete (V_c), the cross section of the shaft is reduced in proportion to the size of the anomaly, however contribution of shear reinforcement (V_s) is not reduced.

- Factored nominal compression resistance of the pile at the anomaly location calculated based on the reduced cross sectional area of the pile along with Load and Resistance Factored Design (LRFD) Specifications with applicable Interims and California Amendments, as follows:

$$P_u \leq \phi P_n$$

Where $\phi=0.85$ and $P_n = 0.85[0.85f'_c\ (A_g - A_{st}) + f_y A_{st}]$

Refer to LRFD BDS (5.7.4.4) for definition of terms. Factored resistance must be checked against factored loads for Strength Limit State load combinations.

Example of Evaluation Process

General:

The purpose of this example is to illustrate type of information to be recorded and transmitted in the design phase, as well as how structural adequacy of a defective CIDH pile is checked. The bridge superstructure is a prestressed reinforced concrete box girder and is supported by two Type-II pile shafts as shown in Fig.1. The site is prone to scour and the soil may liquefy under seismic excitations. The maximum factored axial force of the column considering the overturning effects of seismic forces is 1790 kips, and the plastic moment of the column at this point is 9173 kip-ft. The corresponding overstrength moment and associated shear force are calculated as M_o=1.2 M_p=11008 kip-ft, and V_o=900 kips, respectively. The shaft is 8' in diameter with 56 #14 main reinforcing bars and #8 confining hoops @ 7.5" spacing along the shaft, and $f'c$ = 4 ksi.

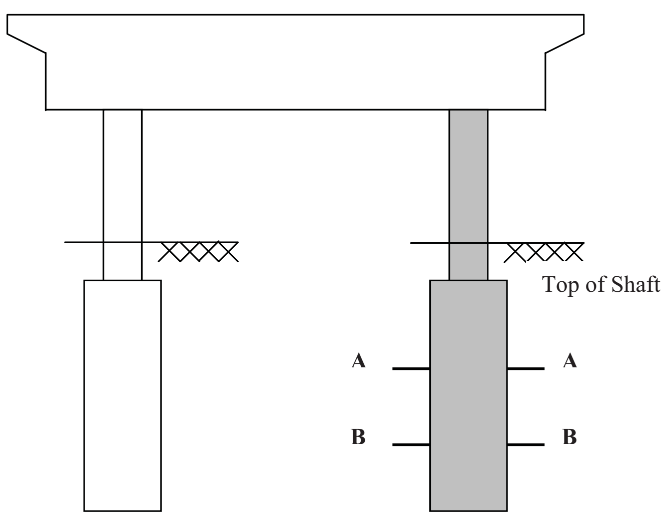

Fig. 1- Elevation of the pile shaft

Design Data to be Recorded and Transmitted:

Since the site is prone to scour and also the soil may liquefy during seismic excitations, the designer analyzed the shaft under column overstrength moment and shear for all possible combinations of scour and liquefaction. The soil springs down to scour depth were eliminated for the 100% scour effect. The effect of liquefaction was also considered by reducing the stiffness of the soil springs. The moment and shear diagrams for all possible combinations of the scour and liquefaction were reported by the designer and are shown in Figs. 2 and 3, respectively. The information was saved in the bridge design branch to be used for construction support.

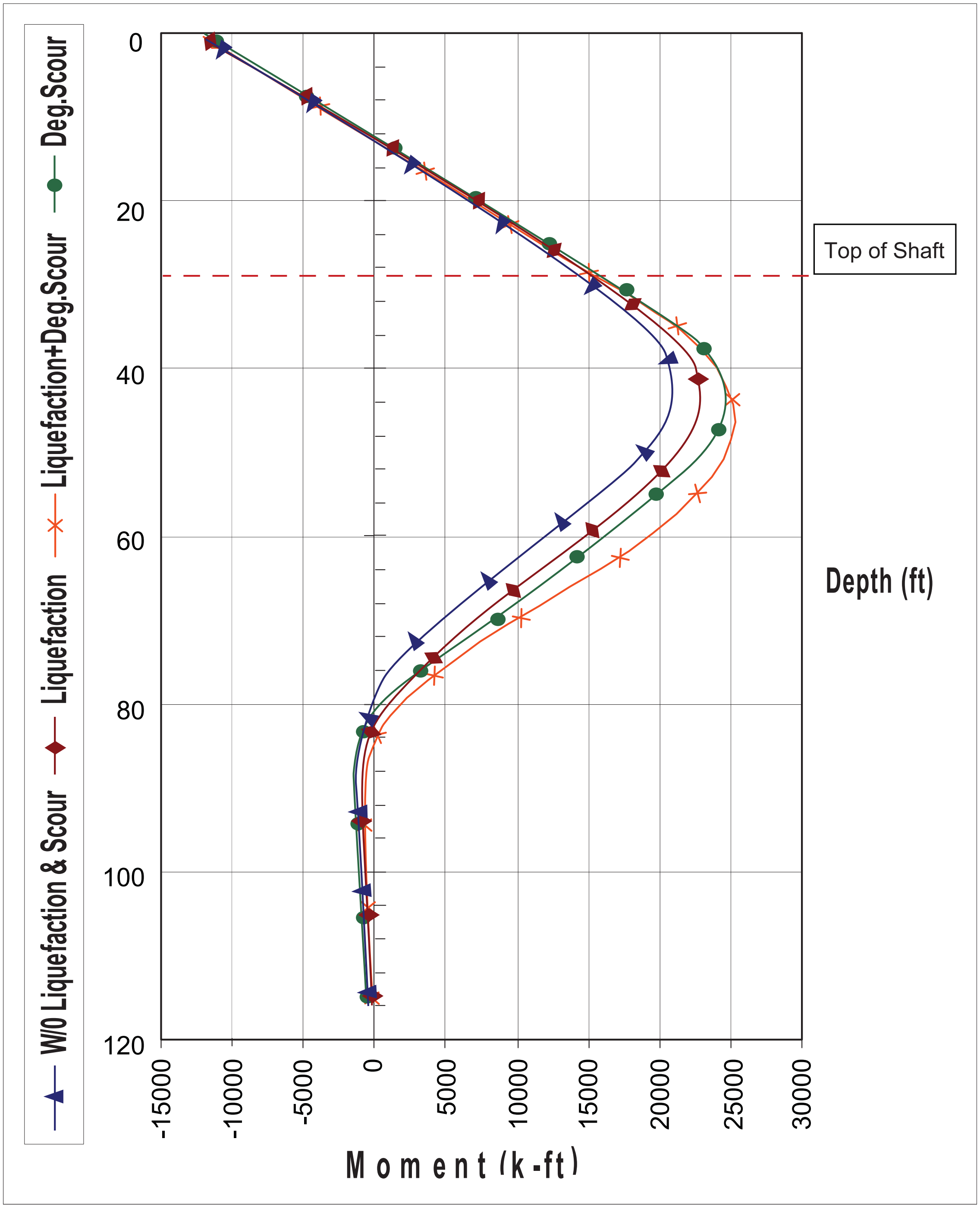

Fig. 2 – Seismic moment demand in the shaft

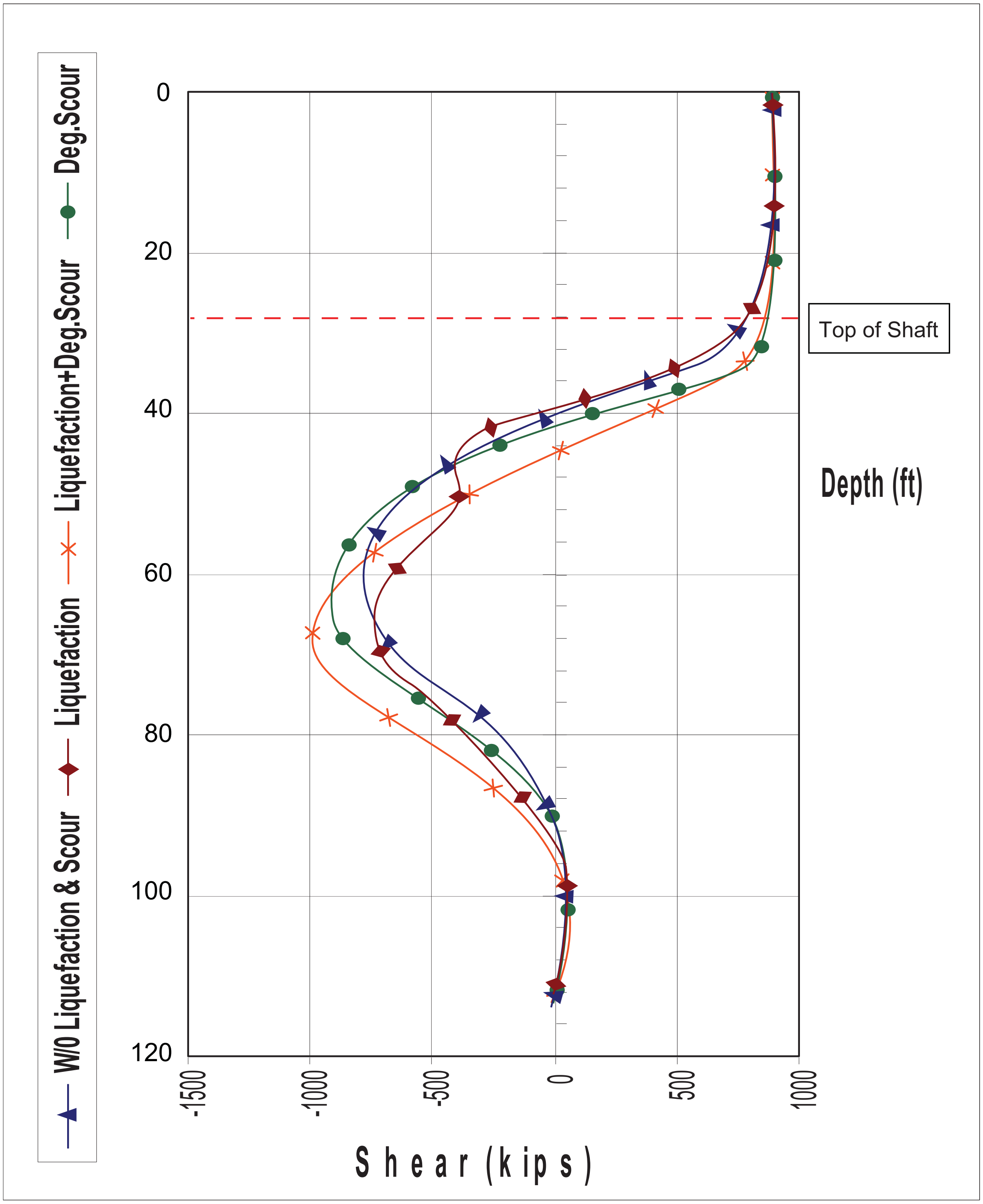

Fig. 3- Seismic shear demand in the shaft

During construction of the shaft, the result of the GGL showed one tube (out of seven) with low reading at the depth of 32- 34 ft. that is 3-5 ft. below top of shaft /(Section A-A, Case I), and two tubes (out of seven) with low readings at a depth of 65 - 67 ft, that is 36-38 ft. below top of shaft (Section B-B, Case II) as shown in Fig. 4. Attachment-I shows the PDDF for this example with information regarding location and size of the anomaly.

Section A-A (Case I)
(Defect = 14%)

Section B-B (Case II)
(Defect = 28%)

Fig. 4 – Schematics of defects in the shaft

Capacity of Defective Shaft:

Sectional analysis tool (such as the X-Section Program) is used to calculate the reduced flexural capacity of the defective pile. In this example the compression steel rebars in the defected area have been ignored. If requested, Foundation Testing Branch of the GS may provide information on the nature of the anomalous material that would help to decide if rebars in the defected area can be included in the sectional analysis. For a single anomaly (Case-I) the section is rotated to place the defective area under compression to capture the minimum flexural capacity value. However, in the case of two or more non-adjacent tubes with low readings (anomalies) in the pile, the cross section is rotated in 30 degree increments to locate the least flexural capacity of the reduced section.

The criteria for capacity calculation is different for Types I and II shafts. For Type-II shafts (capacity protected component) the expected nominal moment (M_{ne}) is used in evaluation and that moment is calculated at concrete compressive strain of 0.003. For Type-I shaft (ductile component) hinging of the shaft is allowed and therefore the plastic capacity of the reduced section of the shaft (M_p) is calculated.

In this example, the expected nominal moment of the reduced section for Case-I was calculated as 19893 kip-ft. For Case-II the capacities of the reduced section at various angles of rotation were calculated and are listed in Table 1.

Table 1 - Type II Shaft with low readings at two tubes

Angle of Rotation (degrees)	M_{ne} @ $\epsilon_c = 0.003$ (k-ft)
30	15082
60	14311
90	16518
120	16870
150	16504
180	16633
210	17066
240	15226
270	14454
300	16810
330	19949
360	18813

Evaluation for Bending (Seismic):

The moment demand at Section A-A is 21500 kip-ft for the most critical condition when liquefaction and scour are considered. The reduced capacity of the section was calculated as 19893 kip-ft; therefore the pile at this location is rejected. The governing moment demand at Section B-B is 13700 kip-ft and the minimum capacity of the reduced section was calculated as 14311 kip-ft (see Table 1), therefore the pile capacity at this location is acceptable.

Evaluation for Shear (Seismic):

The shear capacity of the pile at Sections A-A and B-B are calculated as 1275 kips and 1206 kips respectively. Shear demands at these two points are 813, and 913 kips (Fig.3), respectively. Therefore, the pile is acceptable for shear.

Evaluation for Axial Force (LRFD):

The factored nominal compression resistance of the shaft without anomaly is calculated as 22925 kips. The reduced factored resistance of defective shaft is: $22925 \times (1-0.28) = 16506$ kips. In general, interaction of the axial force and bending moment should be considered when evaluating the shaft for LRFD strength limit state load combinations. However, factored axial resistance is much higher than maximum factored axial load of 3120 kips, and such analysis is not necessary in this example.

Attachment I shows completed PDDF for this example. The completed form is then forwarded to the Foundation Testing Branch of the GS.

(original signed by Kevin J. Thompson)

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